

ADVANCED MINERALOGY

UNDERSTANDING YOUR DATA
FROM MICROSCOPIC TO FIELD SCALE



QEMSCAN SERVICES: UNDERSTANDING YOUR DATA, FROM MICROSCOPIC TO REGIONAL SCALE

Rock property data integrated with petrophysical analysis is essential for the accurate assessment of a reservoir. Only, a detailed understanding of reservoir rock can give a precise prediction of well production and performance. With rock-tied data, a model can increase and delineate reserves and provide improved confidence in formation and field development. Defining and mitigating uncertainty is the biggest challenge in the oil & gas industry and SGS aids in removing risks through our geoscientifically calibrated workflow.

SGS works with an integrated team, allowing optimal analysis and expert interpretation.

The advantages of the workflow are summarized below and selected case studies are presented.

QEMSCAN DATA CREATION in Calgary, CA

QEMSCAN ANALYSIS OF ROCK FRAGMENTS

- Definition of lithotypes

QUANTITATIVE MINERALOGICAL ANALYSIS

- Definition of mineral models

STUDIES BASED ON QEMSCAN DATA, coordinated in Voorburg, NL

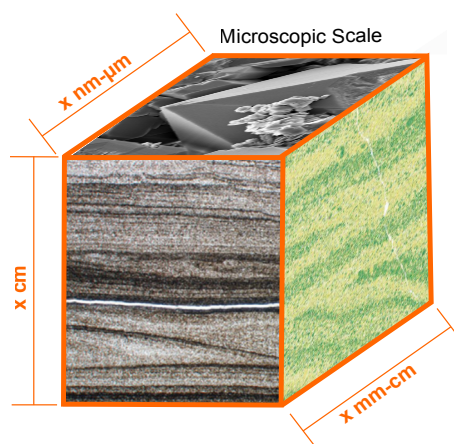
CALIBRATED LOG INTERPRETATION

- Reservoir characterization
- Reservoir quality assessment
- Well performance prediction
- Troubleshooting well performance

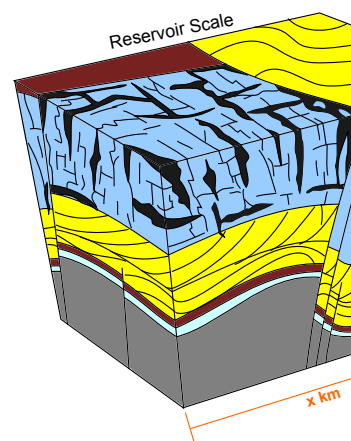
SEDIMENTARY MODELLING

- Chemos
- Well cor
- Reservo

MICROSCOPIC SCALE



RESERVOIR SCALE



INTRODUCTION

As oil and gas exploration becomes increasingly focused on targeting unconventional plays and reinventing historic conventional resources – with the ever present objective of cost savings – the requirement for improved knowledge of the physical characteristics of the reservoir becomes essential. Understanding the composition and texture of reservoir rock is critical as the mineral components intrinsically control the fundamental petrophysical parameters and directly or indirectly influence many of the wireline responses. Therefore, accurate and reproducible quantification of the mineral assemblage is a key input in petrophysical, wireline log calibration and engineering interpretations.

The drive to reduce well-site costs means that fewer wells are being cored and hence, typically only cuttings are available to directly sample the reservoir section. Fortunately, cuttings are an ubiquitous and low cost by-product that can be used as lithological samples for detailed analysis. This is one of the many advantages of using QEMSCAN technology.

QEMSCAN analysis can be paired with other advanced technology and analytical techniques (e.g., XRD, SEM, trace element geochemistry and FTIR) to give detailed insight into reservoir properties, characterization and performance.

Our workflows integrate these data streams, amongst others, to reduce uncertainty and improve geologic models for enhanced reservoir knowledge, inter-well correlation, optimal well placement, and better prediction of production performance.

STRATIGRAPHICAL CORRELATION

Stratigraphy
Correlation
Seismic delineation

NANOINDENTATION FOR ROCK MECHANICS

- Determination of mechanical properties
- Fracturability assessment
- Seal integrity studies

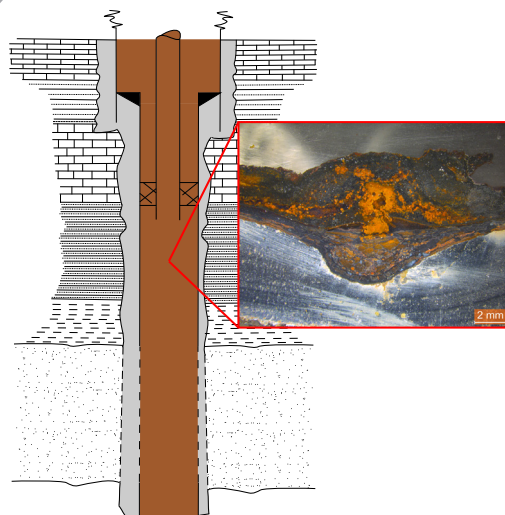
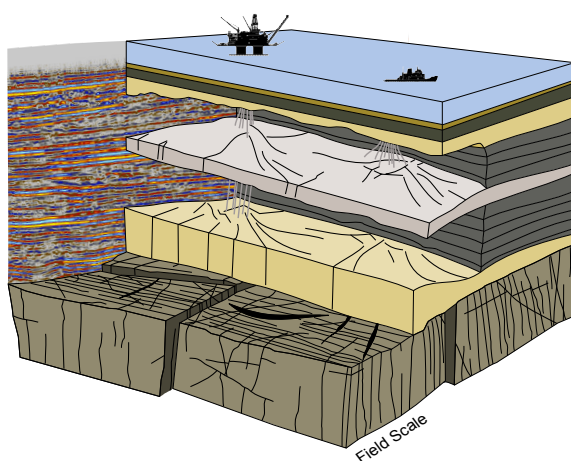
QUANTITATIVE INTERPRETATION

- Seismic Inversion
- Rock properties prediction on reservoir scale
- Identification of sweet spots

CORROSION FORENSICS

- Reservoir Souring Investigation
- Microbial DNA analysis
- Corrosion monitoring

REGIONAL SCALE



For further information and enquiries, please contact:

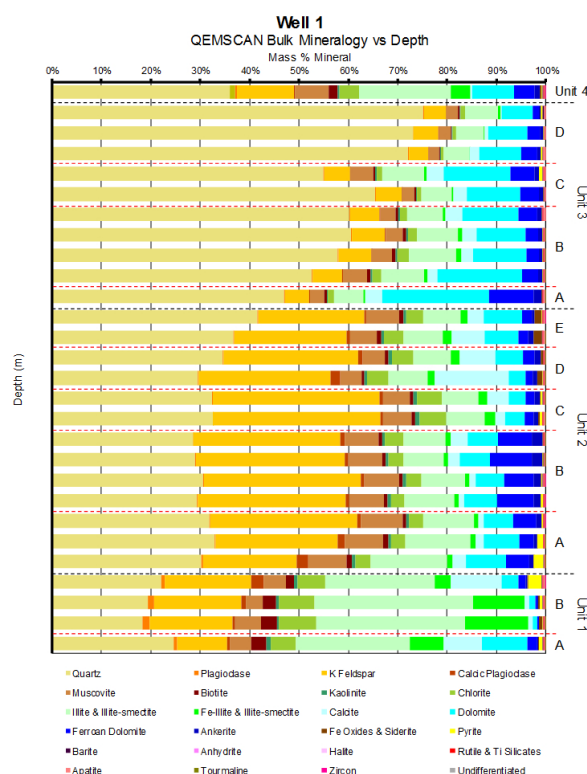
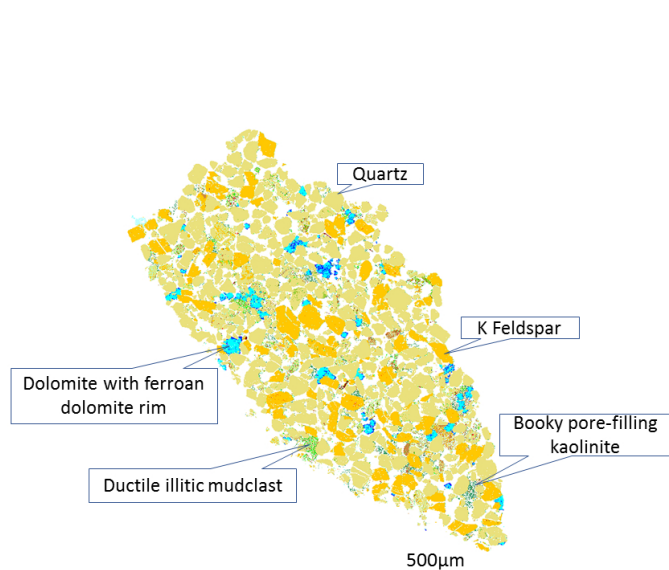
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QUANTITATIVE MINERALOGICAL ANALYSIS: TAKING A CLOSER LOOK AT YOUR RESERVOIR



It is only with the acquisition of high quality, accurate data that reliable models can be constructed. SGS's dedicated team of specialists include mineralogists, petrophysicists, reservoir geologists and production engineers who interpret the analytical outputs. Workflows have been developed for a wide range of plays and applications that include:

DEFINITION OF IMPROVED MINERAL MODELS

- Using accurate mineralogical data as an input to validate and improve mineral models or other petrophysical interpretations
- Integrating wireline and mineralogy data to identify and assess bypassed pay. Is it cost effective to recomplete a well?

CALIBRATED LOG INTERPRETATION

- Investigating archived cuttings to provide detailed and accurate data even where little or no information exists.
- Using mineralogical and textural information to derive pseudo-logs, which can then be interpreted and correlated between wells or even across regions.

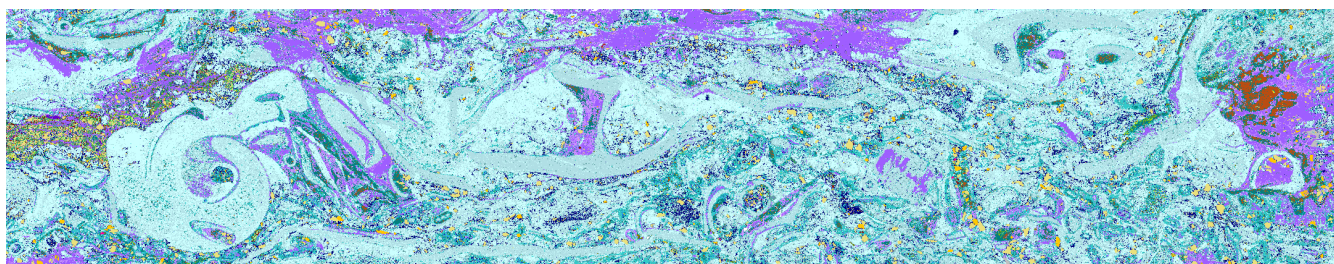
RESERVOIR CHARACTERIZATION

- Identifying the distribution and speciation of clays that influence production performance.
- Determining rock texture and organic content, which control frac-performance, in unconventional studies.
- Investigating the mineralogical and lithological controls on EOR performance and formation damage.
- Troubleshooting poor well – or frac-performance.
- Optimizing engineering designs and minimize or mitigate scale deposition by smart design of screens, scale prediction and water modelling.

WELL CORRELATION AND INSIGHTS INTO RESERVOIR ARCHITECTURE

- Improving the resolution and input into sedimentological and provenance studies, and basin studies as a whole, by using mineralogy, lithostratigraphy and mineral-validated chemostratigraphy.
- Understanding reservoir heterogeneity by improved visualization, and thus assessing impact of mineralogy on reservoir and well performance.
- Establishing lateral correlation between wells and in delineating the reservoir architecture by using lithostratigraphy data from cuttings.
- Assessing how facies variations control reservoir quality and performance.

MINERAL MODEL CALIBRATION

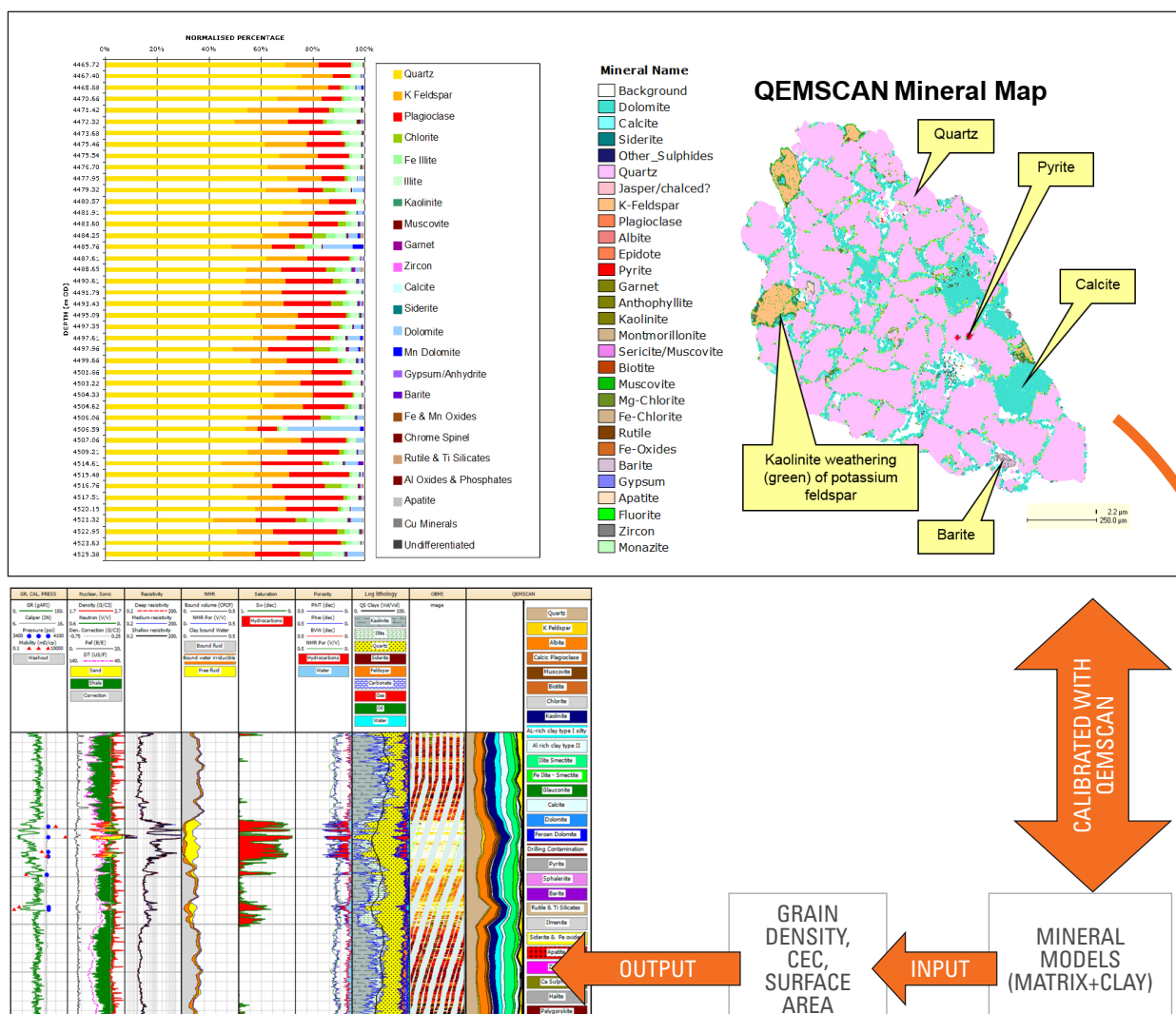


A reliable mineral model is required to determine the petrophysical properties from logs especially for complex mineralogy reservoirs such as gas shales. If the mineral model is not an accurate representation of formation mineralogy, the quantification of petrophysical properties will be inaccurate. Therefore log-computed outputs require calibration to measured mineralogical data.

The mineralogical and textural properties such as grain density, cation exchange capacity (CEC) and surface area are then used to calculate porosity, water saturation and permeability, to derive a more representative hydrocarbon in place value. QEMSCAN measurements provide a fully quantitative, mineralogical and textural analysis using an automated SEM / EDS technique. Analysis can be performed on core fragments, drill cuttings and outcrop samples making

it an extremely versatile measurement that addresses the limitations of the existing techniques such as XRD, XRF and SEM. Once calibrated, the groups of generated minerals are considered to be a valid representation of the reservoir lithology.

For these reason SGS uses QEMSCAN in the calibration of mineral based models.



RESERVOIR QUALITY ASSESSMENT

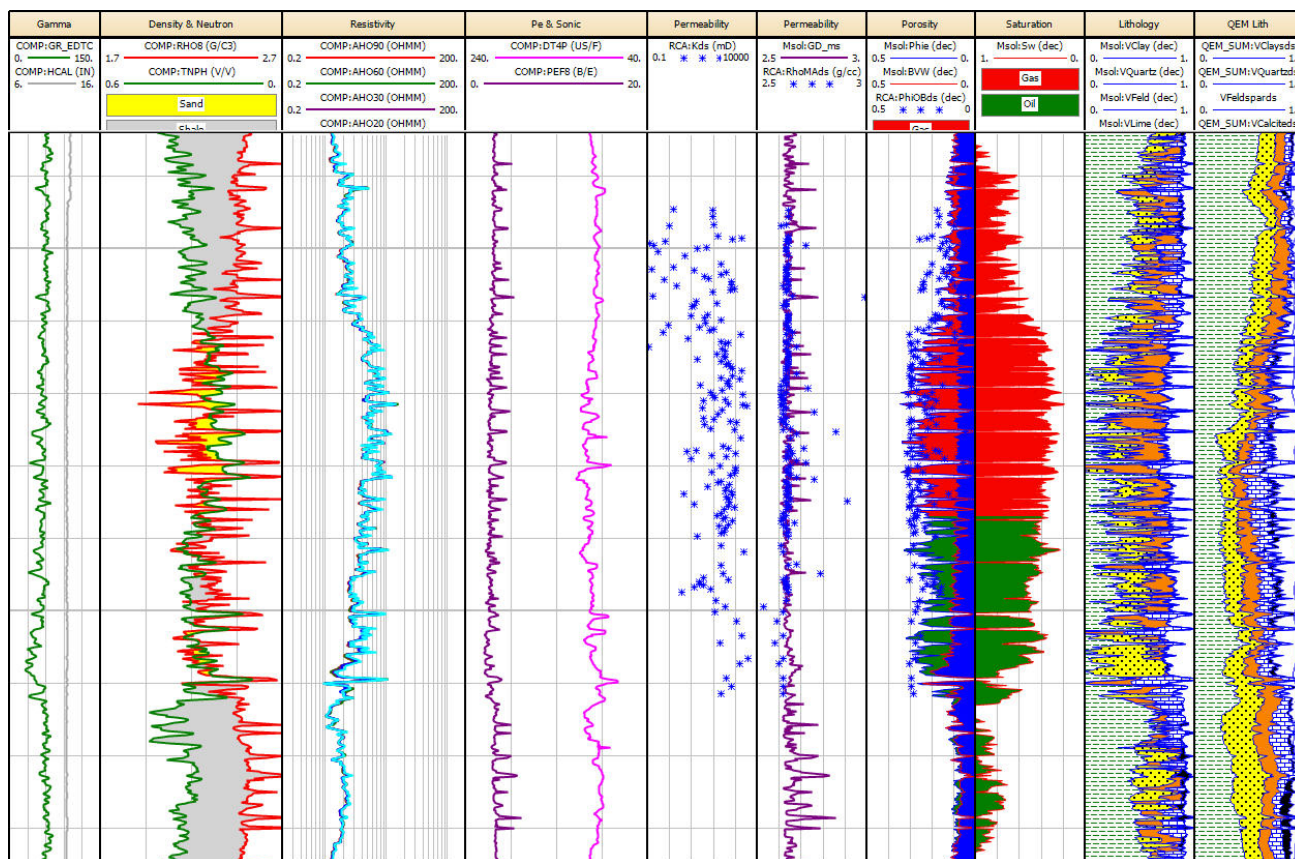
Accurate characterization of reservoirs fundamentally relies on the amount, and quality of available subsurface data. Log responses are influenced by mineralogical factors including grain density, radioactivity, chemistry and spontaneous potential. Advances in logging techniques including the addition of spectroscopy tools, such as ECS, FLEX or GEM, have enhanced the petrophysical and geological understanding of reservoirs. While these tools have provided significantly more data than was previously available, their operation involves the analysis of elemental compositions, meaning they do not directly measure the mineralogy or rock types, but rather derive these outputs through the use of analogues. As such, the accuracy of the tools is not

consistent across all lithotypes, reducing their effectiveness and reliability for deriving accurate petrophysical properties. Where possible, a direct measurement of the rock provides the most reliable input for log calibration.

Certain rock properties can only be derived through the analysis of core, core plugs or sidewall cores. However, even where core is available, the nature of plug based sampling means the entire reservoir interval is not completely analyzed, nor is the full extent of heterogeneity understood. This will result in questions about the representativity of rock composition and reservoir properties when using these data in the calibration of mineralogical models based on log responses. Cuttings, although almost

always available, are commonly overlooked as a potential source of meaningful data when characterizing reservoirs. However, cuttings – when correctly sampled – can be used to provide continuous mineralogical and textural information, as well as data for petrophysical calibration, making it possible to analyze sequences where cores or logging data are limited or not available.

QEMSCAN analysis of archived cuttings in an appraisal / pre-drilling study will reduce risk associated with mineralogy or texture. Further, it can reduce cost through identification of possible high rate of penetration units, and lower abrasion zones for well placement.



EXAMPLE

A reservoir characterization study was performed for two wells (A and B) that drilled through a thick shaly sequence offshore, West Africa. For both wells QEMSCAN analysis was performed on drill cuttings for the interval of interest, and provided a detailed lithological and mineralogical description, along with a prediction of porosity, bulk density and matrix density of the samples. The results of QEMSCAN were used to define and calibrate the petrophysical mineral model used for log interpretation. The QEMSCAN data indicated that there were significant variations in the relative proportions of the primary reservoir minerals (quartz and feldspars) as well as micas and clay minerals. Also, significant quantities of carbonates (calcite and dolomite) and heavy mineral such as siderite and pyrite are present over the entire well section. Such variations are difficult to account for, using the

standard deterministic evaluation approach which was first applied for these wells.

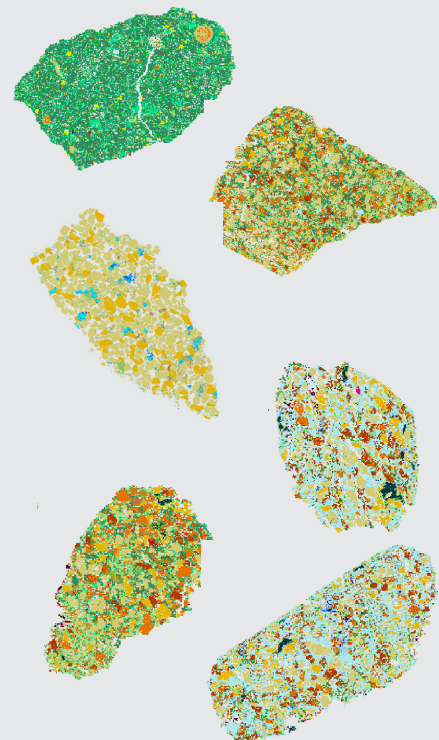
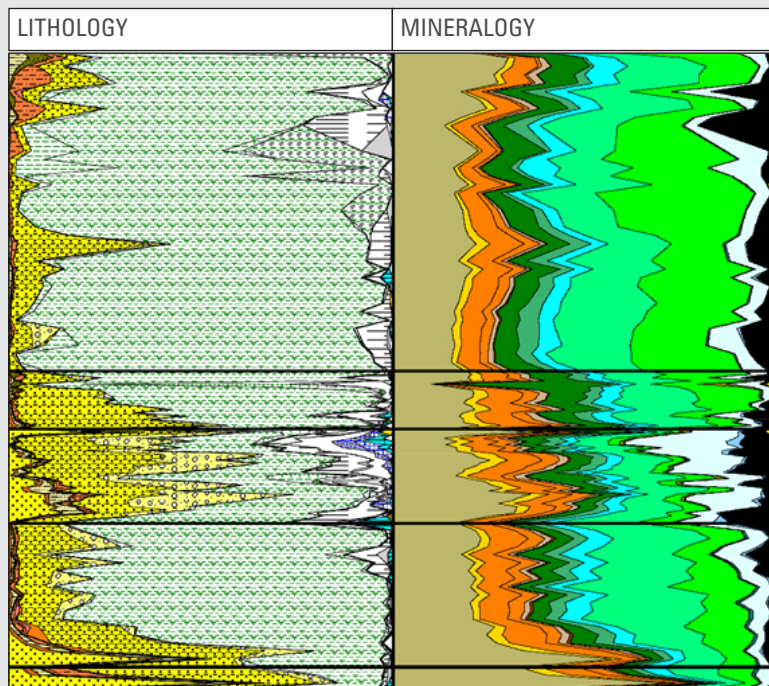
Complex formations such as those encountered in these two wells are preferably evaluated using a probabilistic mineral modeling methodology. The QEMSCAN results comprised the quantification of the relative proportions of 30 lithology types (arenites, arkose, silts mudstones etc.) and 28 mineral components (quartz, feldspars, micas, clay minerals etc.). For the utilization of the QEMSCAN data in defining the mineral components to be used in the probabilistic mineral model, a rationalization of the number of minerals was required, this is because the number of components (rock and pore fill) that can be handled is limited by the number of logs available, which can be used to differentiate the different components and these

minerals were grouped as the following:

- Rock matrix minerals
- Clay minerals
- Carbonate minerals
- Heavy minerals

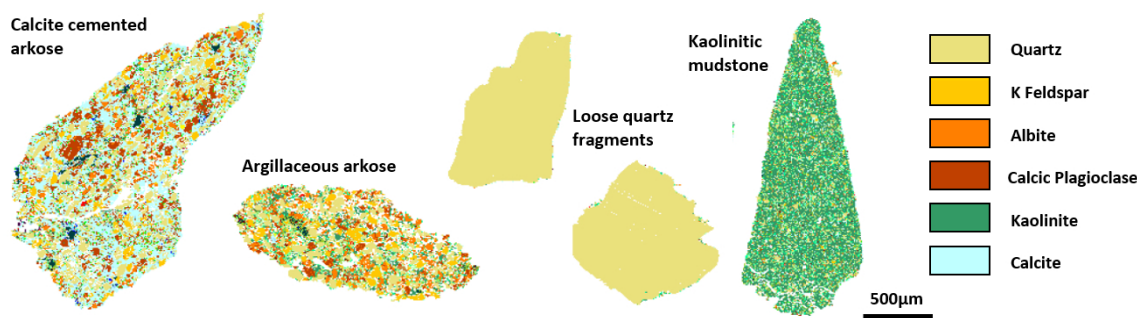
Based on the log data, curves were generated for each of the mineral groups. These curves were calibrated to the QEMSCAN data, ensuring a reliable petrophysical mineral model. The mineral volumes determined from the logs show a good match with the QEMSCAN data.

The application of the probabilistic mineral modeling methodology has resulted in a significant improvement in the correlation between the log derived effective porosity and the core measurements. Also, there is a substantial increase in the total hydrocarbon content compared to the original evaluation.



WELL CORRELATION AND RESERVOIR ARCHITECTURE

Significant quantities of the world’s hydrocarbon are contained in reservoir sequences that have poor stratigraphic control. In those settings, exploration is complex and the efficiency of subsequent resource appraisal and field development is hindered. SGS’s QEMSCAN automated mineralogical analysis of cuttings contributes significantly to establishing the correlation between wells by identifying mineralogical and textural relationships and sequences. This facilitates a crucial step towards the comprehension of the regional-scale distribution of reservoir sands and their lateral continuity.



EXAMPLE

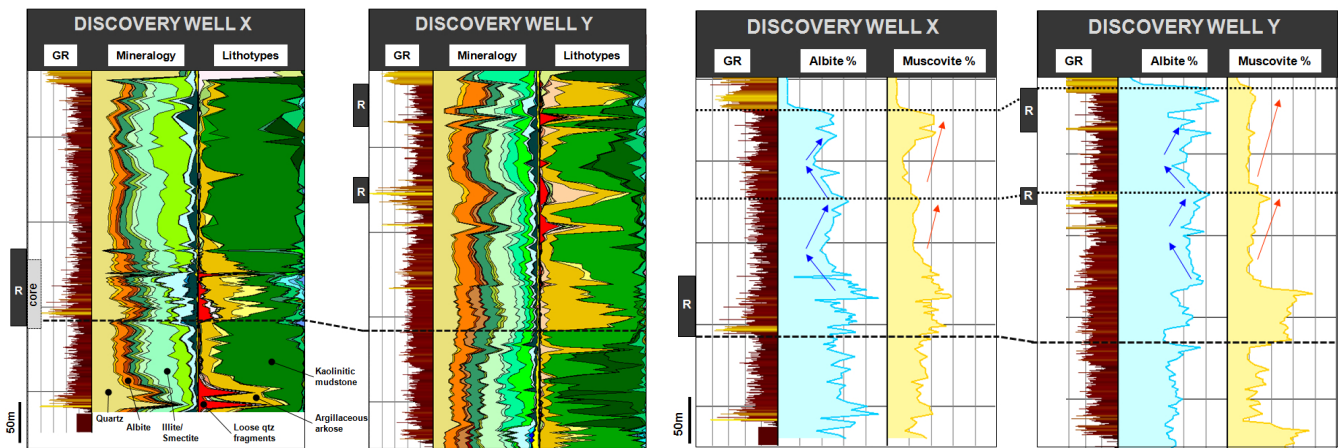
QEMSCAN samples of two discovery wells have been analyzed. The reservoir units were deposited in a complex setting of proximal ramp with shallow fluvio-turbidity currents form imbricated channels and where sedimentation is jointly influenced by storms. We were able to show successions of channelized sequences that can be correlated from well to well.

The discovery well X encountered a thick oil bearing sand-dominated interval. The detailed mineralogical QEMSCAN images of cuttings show that the reservoir petrography is dominated by quartz and feldspar. The reservoir forms a clear fining upward sequence which is interpreted as a channel filling sequence of a

large channel complex interpreted on seismic. The well Y was drilled subsequently, 8km from well X, in the same corridor of imbricated channels. The correlation of the two wells became key for efficiently pursuing exploration efforts and appraise the discoveries. However chaotic character of seismic reflector and poor log responses did not permit for a confident correlation.

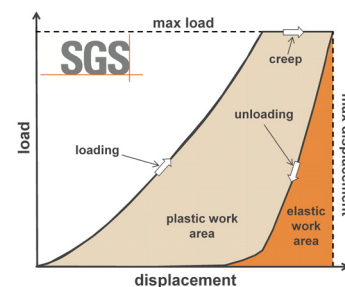
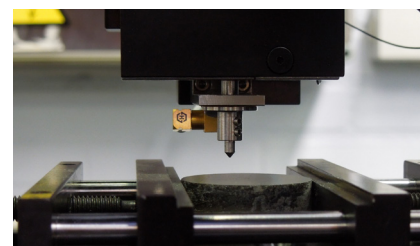
The QEMSCAN analysis of the discovery well Y shows the presence of a clear fining upward sequence in the lower part of the well, equivalent to the one observed on the well X. At the well Y, this sequence is similarly dominated by quartz and feldspar, but it is non-reservoir (clay dominated).

The identification of this remarkable fining upward sequence on the well Y, not visible on the gamma ray log, anchored the well correlation and is in line with biostratigraphic results. Furthermore, the analysis of individual mineralogical signatures in the shallower interval reveals the presence of sequences that correlate very nicely between both wells. Those results show that the sedimentary system and its deposits recorded regional changes (probably mainly tectonic). The correspondence between the quartz abundance and the regional relative sea level for the entire Late Cretaceous to Oligocene section illustrates this point at a larger scale.



NANOINDENTATION FOR ROCK MECHANICS

The mechanical properties of rocks are closely related to the mineralogy and play a vital role in wellbore stability, seal integrity, and fraccability. For oil and gas operations these properties are determined by laboratory analysis of core samples, which are expensive to acquire and consequently often are not available. To circumvent the lack of core samples, SGS developed a novel workflow to measure rock mechanical properties from a wide range of sample types by utilizing nanoindentation. Nanoindentation is a method to determine the mechanical properties of materials from small samples by pressing a hard tip with known mechanical properties into the sample while monitoring the applied load and the displacement of the tip into the sample. By applying nanoindentation on QEMSCAN samples, a detailed integration of the mechanical properties with the mineralogy is obtained, resulting in accurate measurements of the rock mechanical properties. This provides valuable information for seal integrity studies, identification and delineation of sweet spots for completions, and hydraulic stimulation designs.



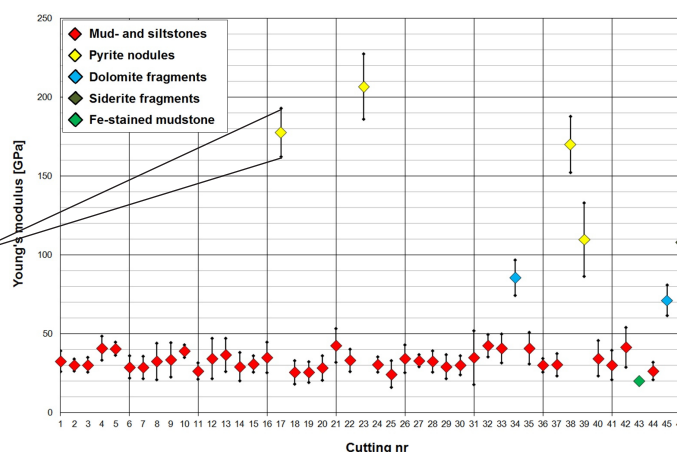
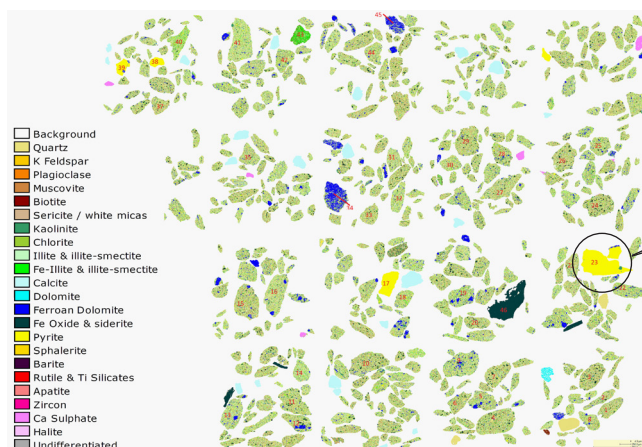
EXAMPLE

QEMSCAN analysis was carried out for 80 drill cuttings samples from five different wells to assess the potential of the Silurian Hot Shales as an unconventional resource and identify the most prospective intervals, i.e. sweet spots. The bulk of the drill cuttings (approximately 90 %) were classified as a type of mud – or siltstone, consisting of a fine-grained matrix of clay minerals and quartz. Two lithostratigraphic intervals were identified: (i) the Wenlockian interval, characterized by a higher quartz content, and (ii) the Llandoveryan interval, characterized by an increase in pyrite.

Next, representative drill cuttings samples were selected to assess the fraccability of the Silurian Hot Shales using nanoindentation. Based on the QEMSCAN data, 46 drill cuttings of different lithotypes were selected for nanoindentation. The results show a clear distinction between the mechanical properties of different lithotypes. The mud – and siltstone lithotypes have an average Young's modulus varying between 32 and 34 GPa, whereas the Young's modulus values of the drill cuttings consisting of one specific mineral (i.e. pyrite nodules, dolomite fragments, and siderite fragments) are significantly

higher. These values are in line with values found in literature for shales and specific minerals, such as pyrite and dolomite.

As the bulk of the Silurian Hot Shales consists of mud – and siltstone it is the mechanical properties of these lithotypes that determine the mechanical behaviour of the rock. The Silurian Hot Shales thus are well suited for shale gas production, exceeding the preferred Young's modulus value of 21 GPa.



RESERVOIR SOURING INVESTIGATION

The origin of H₂S is related to chemical reactions in reservoirs, in hydrocarbon source rocks or during migration of fluids into a trap. Furthermore certain minerals in rocks have a scavenging or a catalytic effect. Six processes of H₂S generation are known, and they may result in different H₂S concentrations:

BSR	TSR	THERMAL CRACKING OF ORGANIC SULFUR COMPOUNDS (OSC)	MINERAL DISSOLUTION	(RE-) MIGRATION	H ₂ S INJECTION OR DISPOSAL
Bacterial Sulfate Reduction in reservoirs occurs only at low temperatures (< 80 °C). BSR produces maximal H ₂ S	Thermochemical Sulfate Reduction in reservoirs at high temperature and pressure conditions in the presence of sulfate	During the maturation process the organic sulfur compounds of the kerogen and the oils are thermally cracked and form H ₂ S	$\text{FeS} + 2\text{H}^+ \rightarrow \text{H}_2\text{S} + \text{Fe}^{2+}$ generate low H ₂ S concentrations	Lateral or vertical migration from deeper H ₂ S bearing horizons	Infection during field operations using contaminated fluids or gasses
MAX. 5%. H ₂ S	UP TO 98%. H ₂ S	MAX. 5%. H ₂ S	< 50 PPM H ₂ S	UP TO 98%. H ₂ S	MAX. 5%. H ₂ S

SGS's chemical laboratory and sour gas expertise centers are located in Dubai, Malaysia, Belgium, Germany, USA and The Netherlands

In addition to the standard chemical analysis SGS has a profound expertise on high-end laboratory analysis such as GC-MS, ICP-OES Isotope Analysis, CSIA, TOF-SIMS, Biomarkers and DNA analysis of H₂S producing bacteria.



SGS's laboratory facilities perform:

- Core flooding experiments,
- Scaling and corrosions experiments
- Mineralogy (QEMSCAN™, SEM, XRD)
- Mechanical rock properties (Nano-indentation).
- High resolution CT-Scan

EXAMPLE

H₂S generation from different sources affects the crystallography of the by-product minerals, e.g. generation of calcite macrocrystal during BSR process or creation of calcite rim during TSR process.

Certain minerals which are naturally present in a reservoir are capable of

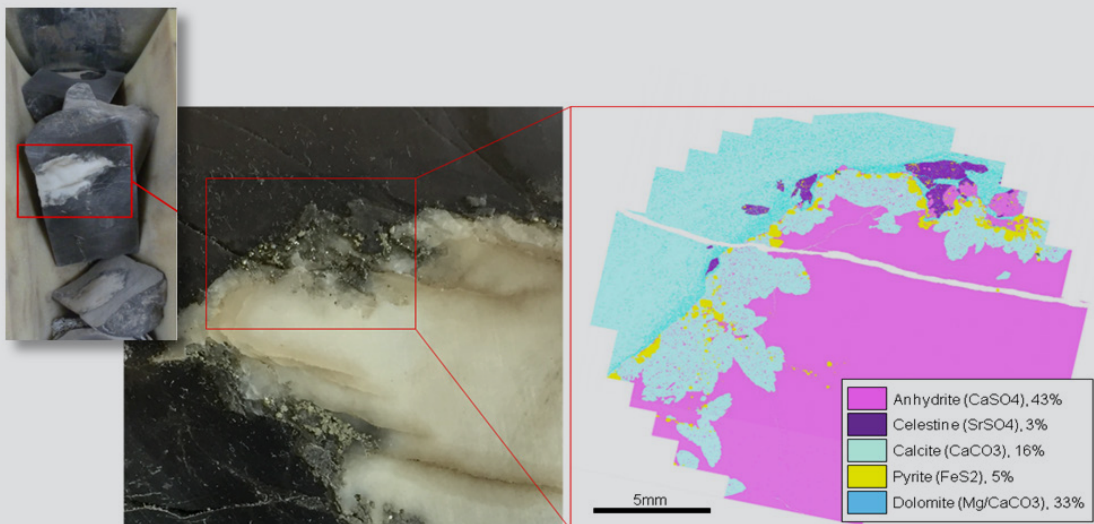
scavenging considerable amounts of H₂S by formation of metal sulfides.

Common scavenging minerals are Siderite, Magnetite, Glauconite and the clay phase Chlorite.

SGS is applying a combination of CT-SCAN, QEMSCAN™ and SEM, for mineralogical, lithological

and petrographical analysis and interpretation to

- Identify the origin of the H₂S
- Describe the induced mineralization processes
- Understand the natural scavenging effects.



Anhydrite nodule with rim of calcite and pyrite

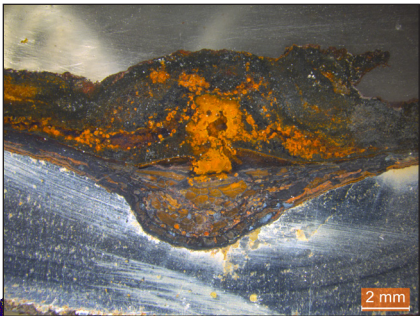
CORROSION FORENSICS

Corrosion issues are well known by the industry and usually require preventive measures. These measures may be biocide to prevent microbial issues, cathodic protection or scavengers to prevent chemical attack.

The effectiveness of these measures is difficult to assess as cessation of the treatment is not recommended due to the safety and financial risk corrosion brings. Typically, only when a problem

occurs a detailed investigation is performed to re-assess the preventive measures taken in the past.

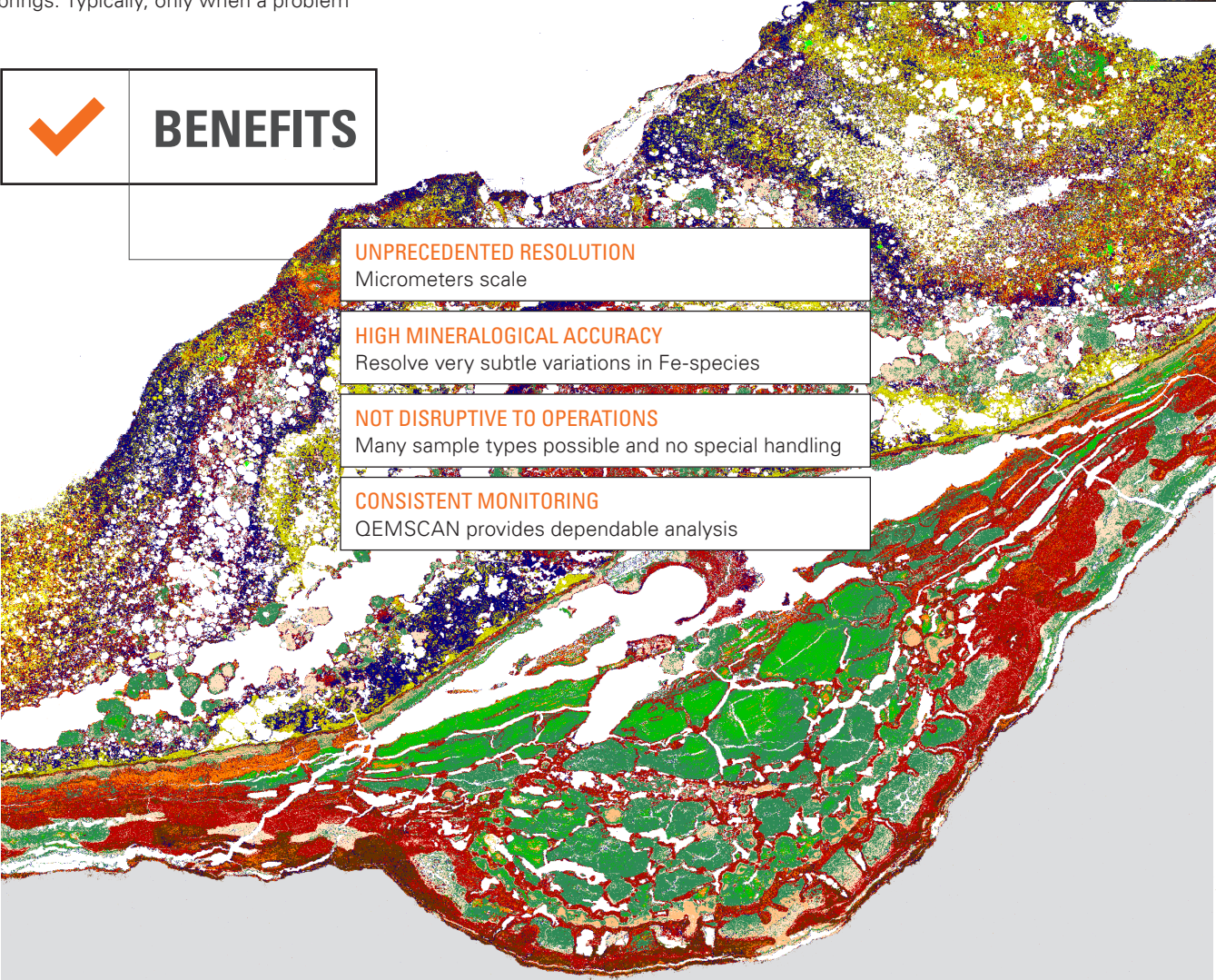
SSG is uniquely equipped to perform such corrosion forensics. By using our tailored QEMSCAN analysis to assess corrosion products we can identify the corrosion mechanism and recommend ways to prevent further failures in the future.





BENEFITS

- UNPRECEDENTED RESOLUTION**
Micrometers scale
- HIGH MINERALOGICAL ACCURACY**
Resolve very subtle variations in Fe-species
- NOT DISRUPTIVE TO OPERATIONS**
Many sample types possible and no special handling
- CONSISTENT MONITORING**
QEMSCAN provides dependable analysis



CORROSION MONITORING

Apart from ‘post-mortem’ corrosion forensics, QEMSCAN can also be applied as a monitoring tool. Through analysis of pitting and filter residue or corrosion coupons, the mineralogical composition of scales and corrosion products can be tracked. This provides insights into active corrosion mechanisms and their severity.

DNA ANALYSIS

Microbial Induced Corrosion is estimated to be responsible for 60% of the corrosion related failures and corrosion rates can reach up to 5mm/yr. Occasionally corrosion products by microbial populations are very similar to those of chemical, non-microbial, corrosion mechanism and QEMSCAN alone does not provide clear insights.

SGS has therefore developed specific DNA based technologies using state of the art Next Generation Sequencing to detect and characterize microbial communities in corrosion products. Combining QEMSCAN and DNA analysis reduces uncertainty and allows for the selection of appropriate biocides.

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WHEN YOU NEED TO BE SURE

